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COLLEGE PHYSICS

ELECTRICITY AND MAGNETISM, LIGHT, AND ATOMIC PHYSICS

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THIRD EDITION

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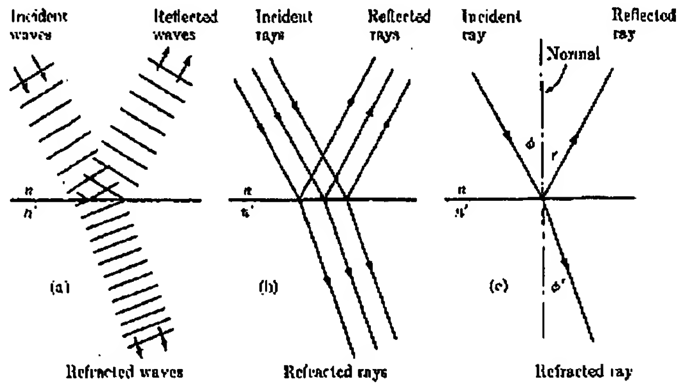

Fig. 40-5. (a) A train of plane waves is in part reflected and in part refracted at the boundary between two media. (b) The waves in (a) are represented by rays. (c) For simplicity, only a single incident, reflected, and refracted ray are drawn.

bent *toward* the normal. If the light is traveling in the opposite direction, the reverse is true and the ray is bent *away from* the normal.

To summarize the laws of reflection and refraction in terms of rays:

When a ray of light is reflected, the angle of reflection is equal to the angle of incidence. The incident ray, the reflected ray, and the normal to the surface at the point of incidence, all lie in the same plane.

When a ray of light is refracted, $n \sin \phi = n' \sin \phi'$. *The incident ray, the refracted ray, and the normal to the surface at the point of incidence, all lie in the same plane.*

40-4 Total internal reflection. Figure 40-6 shows a number of rays diverging from a point source P in a medium of index n and striking the surface of a second medium of index n', where $n > n'$. From Snell's law,

$$\sin \phi' = \frac{n}{n'} \sin \phi.$$

Since n/n' is greater than unity, $\sin \phi'$ is larger than $\sin \phi$ and evidently equals unity (i.e., $\phi' = 90°$) for some angle ϕ less than 90°. This is illustrated by ray 3 in the diagram, which emerges just grazing the surface at an angle of refraction of 90°. The angle of incidence for which the refracted ray emerges tangent to the surface is called the *critical angle* and is designated by ϕ_c in the diagram. If the angle of incidence is greater than the critical angle, the sine of the angle of refraction, as computed by Snell's law, is greater than unity. This may be interpreted to mean that beyond the critical angle the ray does not pass into the

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upper medium but is *totally internally reflected* at the boundary surface. Total internal reflection can occur only when a ray is incident on the surface of a medium whose index is *smaller* than that of the medium in which the ray is traveling.

The critical angle for two given substances may be found by setting $\phi' = 90°$ or $\sin \phi' = 1$ in Snell's law. We then have

$$\boxed{\sin \phi_c = \frac{n'}{n}.} \qquad (40\text{-}3)$$

The critical angle of an air-glass surface, taking 1.50 as a typical index of refraction of glass, is

$$\sin \phi_c = \frac{1}{1.50} = 0.67, \qquad \phi_c = 42°.$$

This angle, very conveniently, is slightly less than 45°, which makes possible the use in many optical instruments of prisms of angles 45°–45°–90° as totally reflecting surfaces. The advantages of totally reflecting prisms over metallic surfaces as reflectors are, first, that the light is *totally* reflected, while no metallic surface reflects 100% of the light incident on it, and second, the reflecting properties are permanent and not affected by tarnishing. Offsetting these is the fact that there is some loss of light by reflection at the surfaces where light enters and leaves the prism, although recently discovered methods of coating the surfaces with so-called "nonreflecting" films can reduce this loss considerably.

The simplest type of reflecting prism is shown in Fig. 40-7. Its angles are 45°–45°–90°. Light incident normally on one of the shorter faces

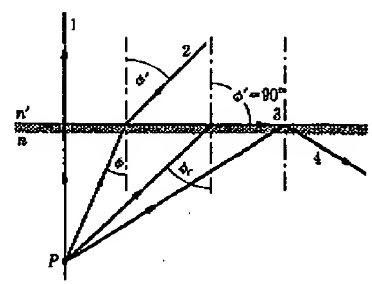

Fig. 40-6. Total internal reflection. The angle of incidence ϕ_c, for which the angle of refraction is 90°, is called the critical angle.

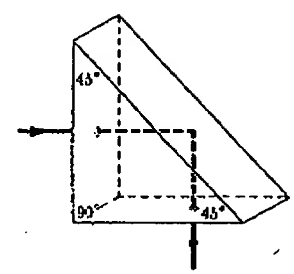

Fig. 40-7. A totally reflecting prism.

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